D-Meson Azimuthal Anisotropy in Midcentral Pb-Pb Collisions root S-NN=5.02 TeV

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D-Meson Azimuthal Anisotropy in Midcentral Pb-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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The azimuthal anisotropy coefficient v_2 of prompt D^0, D^+, D^{*+}, and D_s^+ mesons was measured in midcentral (30%–50% centrality class) Pb-Pb collisions at a center-of-mass energy per nucleon pair $\sqrt{s_{NN}} = 5.02$ TeV, with the ALICE detector at the LHC. The D mesons were reconstructed via their hadronic decays at midrapidity, $|y| < 0.8$, in the transverse momentum interval $1 < p_T < 24$ GeV/c. The measured D-meson v_2 has similar values as that of charged pions. The D_s^+ v_2, measured for the first time, is found to be compatible with that of nonstrange D mesons. The measurements are compared with theoretical calculations of charm-quark transport in a hydrodynamically expanding medium and have the potential to constrain medium parameters.

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Quantum chromodynamics predicts that strongly interacting matter under extreme conditions of a high temperature and energy density undergoes a transition from the hadronic phase to a color-deconfined medium, called quark-gluon plasma (QGP) [1–4]. Heavy-ion collisions at ultrarelativistic energies provide suitable conditions for the QGP formation and for characterizing its properties.

Heavy quarks (charm and beauty) are predominantly produced in hard scatterings before the QGP formation [5,6]. Therefore, they experience all stages of the medium evolution, interacting with its constituents via elastic [7] and inelastic (radiation of gluons) [8,9] processes (see [6,10] for recent reviews).

Evidence of in-medium interactions and energy loss of charm quarks is provided by the strong modification of the transverse momentum (p_T) distributions of heavy-flavor hadrons in heavy-ion collisions with respect to pp collisions. A large suppression of heavy-flavor hadron yields was observed for $p_T > 4$–5 GeV/c in central nucleus-nucleus collisions at the RHIC [11–14] and the LHC [15–19].

Measurements of anisotropies in the azimuthal distribution of heavy-flavor hadrons assess the transport properties of the medium. The collective dynamics of the expanding medium converts the initial-state spatial anisotropy [20] into final-state particle momentum anisotropy. This anisotropy is characterized by the Fourier coefficients v_n of the distribution of the particle azimuthal angle φ relative to the initial-state symmetry plane angle Ψ_n (for the nth harmonic) [21,22]. In noncentral collisions, the largest contribution corresponds to $v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$, called elliptic flow [22,23]. The D-meson v_2 at low p_T provides insight into the possible collective flow imparted by the medium to charm quarks [24], while at high p_T it is sensitive to the path-length dependence of parton energy loss [25,26]. At low and intermediate p_T, a fraction of charm quarks could hadronize via recombination with light quarks from the medium, leading to an increase of the D-meson v_2 with respect to that of charm quarks [27–29]; the comparison of the v_2 of D mesons without and with strange-quark content could be sensitive to these effects and to the charm coupling to the QGP and hadronic matter [30].

A positive heavy-flavor elliptic flow was observed in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV [11,31,32] and in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [19,33–36]. Calculations based on heavy-quark transport in a hydrodynamically expanding medium describe the measurements [37–46]. Precise measurements of heavy-flavor v_2 constrain model parameters, e.g., the heavy-quark spatial diffusion coefficient D_s in the QGP, which is related to the relaxation (equilibration) time of heavy quarks $\tau_Q = (m_Q/T)D_s$, where m_Q is the quark mass and T is the medium temperature [47].

In this Letter, we report on the v_2 of D^0, D^+, D^{*+}, and, for the first time at the LHC, D_s^+ mesons, and their antiparticles, in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, for the 30%–50% centrality class. The analysis uses Pb-Pb collisions collected with the ALICE detector [48,49] in 2015. The interaction trigger consisted in coincident signals in the two scintillator arrays of the V0 detector, covering full azimuth in the pseudorapidity (η) regions $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. Events from beam-gas interactions are removed using time information from the V0 and the neutron zero-degree calorimeters.

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Only the events with a primary vertex reconstructed within ± 10 cm from the detector center along the beam direction are analyzed. Events are selected in the centrality class 30%–50%, defined in terms of percentiles of the hadronic Pb-Pb cross section, using the amplitude of the V0 signals [50,51]. The number of selected events is 20.7×10^6, corresponding to an integrated luminosity $L_{\rm int} \approx 13\ \mu{\rm b}^{-1}$ [51].

The D mesons and their antiparticles are reconstructed using the decay channels $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D^{*+} \to D^0\pi^+$, and $D_s^+ \to \phi\pi^+ \to K^-K^+\pi^+$. The analysis procedure [34,52] searches for decay vertices displaced from the interaction vertex, exploiting the mean proper decay lengths of about 123, 312, and 150 μm of D^0, D^+, and D_s^+ mesons, respectively [53]. Charged-particle tracks are reconstructed using the inner tracking system (ITS) and the time projection chamber (TPC), which are located within a solenoid magnet that provides a 0.5 T field, parallel to the beam direction. D^0, D^+, and D_s^+ candidates are defined using pairs and triplets of tracks with $|\eta| < 0.8$, $p_T > 0.4$ GeV/c, 70–159 TPC space points, and 2–6 hits in the ITS (at least one in the two innermost layers). D^{*+} candidates are formed by combining D^0 candidates with tracks with $|\eta| < 0.8$, $p_T > 0.1$ GeV/c, and at least three ITS hits. The selection of tracks with $|\eta| < 0.8$ limits the D-meson acceptance in rapidity, which varies from $|y| < 0.6$ for $p_T = 1$ GeV/c to $|y| < 0.8$ for $p_T > 5$ GeV/c. The main variables used to select the D candidates are the separation between the primary and decay vertices, the displacement of the tracks from the primary vertex, and the pointing of the reconstructed D-meson momentum to the primary vertex. For the selection of $D_s^+ \to \phi\pi^+ \to K^-K^+\pi^+$ decays, one of the two pairs of opposite-sign tracks must have an invariant mass compatible with the ϕ-meson mass [53]. Further background reduction results from the particle identification. A $\pm 3\sigma$ window around the expected mean values of the specific ionization energy loss dE/dx in the TPC gas and time of flight from the interaction point to the time-of-flight (TOF) detector is used for each track, where σ is the resolution on the two variables. For D_s^+ candidates, tracks not matched to a hit in the TOF (mostly at low momentum) are required to have a 2σ compatibility with the expected dE/dx in the TPC. These selections result in signal-to-background ratios between 0.04 and 2.8 and a statistical significance between 3 and 20, depending on the D-meson species and p_T.

The second harmonic symmetry plane Ψ_2 is estimated, for each collision, by the event plane (EP) angle, denoted ψ_2, using the signals produced by charged particles in the eight azimuthal sectors of each V0 array. Effects of nonuniform V0 acceptance are corrected for using the gain equalization method [54]. The v_2 was calculated by classifying D mesons in two groups, according to their azimuthal angle relative to the EP $\Delta\varphi = \varphi_D - \psi_2$: in plane ($]-(\pi/4), (\pi/4)]$ and $](3\pi/4), (5\pi/4)]$) and out of plane ($](\pi/4), (3\pi/4)]$ and $](5\pi/4), (7\pi/4)]$). Integrating the $dN/d\varphi$ distribution in these two $\Delta\varphi$ intervals, v_2 can be expressed as [34]:

$$v_2\{\mathrm{EP}\} = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{\text{in-plane}} - N_{\text{out-of-plane}}}{N_{\text{in-plane}} + N_{\text{out-of-plane}}}, \tag{1}$$

where $N_{\text{in-plane}}$ and $N_{\text{out-of-plane}}$ are the D-meson yields in the two $\Delta\varphi$ intervals. The factor $(1/R_2)$ is the correction for the resolution in the estimation of the symmetry plane Ψ_2 via the EP angle ψ_2. It is calculated using three subevents of charged particles in the V0 and in the positive and negative η regions of the TPC [22]. The separation of at least 0.9 units of pseudorapidity ($|\Delta\eta| > 0.9$) between the D mesons and the particles used in the ψ_2 calculation suppresses nonflow contributions to v_2 (i.e., correlations not induced by the collective expansion but rather by decays and jet production).

Simulations showed that the D-meson reconstruction and selection efficiencies do not depend on $\Delta\varphi$ [34]; therefore, Eq. (1) can be applied using the D-meson raw yields, without an efficiency correction. The raw yields were obtained from fits to the D^0, D^+, and D_s^+ candidate invariant-mass distributions and to the mass difference $\Delta M = M(K\pi\pi) - M(K\pi)$ distributions for D^{*+} candidates. In the fit function, the signal was modeled with a Gaussian and the background with an exponential term for D^0, D^+, and D_s^+ candidates and with the function $a\sqrt{\Delta M - m_\pi}\, e^{b(\Delta M - m_\pi)}$ for D^{*+} candidates. The mean and the width of the Gaussian were fixed to those obtained from a fit to the sum of the invariant-mass distributions in the two $\Delta\varphi$ intervals, where the signal has a higher statistical significance. In the D^0 invariant-mass fit, the contribution of signal candidates with the wrong K-π mass assignment (about 2%–5% of the raw signal depending on p_T) was taken into account by including an additional term, parametrized from simulations with a double-Gaussian shape, in the fit function [34].

The measured D-meson yield includes the contributions of prompt D mesons, from c-quark hadronization or strong decays of D^* states, and of feed-down D mesons from beauty-hadron decays. The observed v_2, measured with Eq. (1), is a linear combination of the prompt and feed-down contributions: $v_2^{\rm obs} = f_{\rm prompt} v_2^{\rm prompt} + (1 - f_{\rm prompt}) v_2^{\text{feed-down}}$, where $f_{\rm prompt}$ is the fraction of prompt D mesons in the raw yields and $v_2^{\text{feed-down}}$ is the elliptic flow of D mesons from beauty-hadron decays. To calculate $v_2^{\rm prompt}$, a hypothesis on $v_2^{\text{feed-down}}$ is used. The measured v_2 of nonprompt J/ψ [19] and the available model calculations [37,55,56] suggest that $0 < v_2^{\text{feed-down}} < v_2^{\rm prompt}$. Assuming a uniform probability distribution of $v_2^{\text{feed-down}}$ in this interval, the central value for $v_2^{\rm prompt}$ is calculated considering $v_2^{\text{feed-down}} = v_2^{\rm prompt}/2$; thus, $v_2^{\rm prompt} = 2v_2^{\rm obs}/(1 + f_{\rm prompt})$. The $f_{\rm prompt}$ fraction is estimated, as a function of p_T, as described in Ref. [57], using the FONLL [58] calculation for the beauty-hadron cross section, the beauty-hadron decay kinematics from EvtGen [59], the reconstruction efficiencies for feed-down D mesons from the simulation, and a hypothesis for the nuclear modification factor of the feed-down D mesons, $R_{\mathrm{AA}}^{\text{feed-down}}$. The nuclear modification factor is defined as the ratio of the p_T-differential yields in nucleus-nucleus and pp collisions scaled by the average number of nucleon-nucleon collisions in the considered centrality class [60]. By comparison of the R_{AA} of prompt D mesons [61] and J/ψ mesons from beauty-hadron decays [19] in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, the assumptions $R_{\mathrm{AA}}^{\text{feed-down}} = 2R_{\mathrm{AA}}^{\text{prompt}}$ for nonstrange D mesons and $R_{\mathrm{AA}}^{\text{feed-down}} = R_{\mathrm{AA}}^{\text{prompt}}$ for the D_s^+ meson are made to compute f_{prompt}.

The systematic uncertainty from feed-down on v_2^{prompt} was estimated by varying the central value of $v_2^{\text{feed-down}} = v_2^{\text{prompt}}/2$ by $\pm v_2^{\text{prompt}}/\sqrt{12}$, corresponding to ± 1 rms of a uniform distribution in $(0,\ v_2^{\text{prompt}})$. The uncertainty on f_{prompt} was obtained from the variation of the FONLL calculation parameters and from the variation of the $R_{\mathrm{AA}}^{\text{feed-down}}$ hypothesis in $1 < R_{\mathrm{AA}}^{\text{feed-down}}/R_{\mathrm{AA}}^{\text{prompt}} < 3$ for nonstrange D mesons [15] and $\frac{1}{3} < R_{\mathrm{AA}}^{\text{feed-down}}/R_{\mathrm{AA}}^{\text{prompt}} < 3$ for D_s^+ mesons [52]. The value of the absolute systematic uncertainty from feed-down ranges from 0.001 to 0.030.

The other sources of systematic uncertainty are related to the signal extraction from the invariant-mass distribution, nonflow effects, and centrality dependence in the EP resolution correction R_2.

The signal extraction uncertainty was estimated by varying the background fit function and leaving the Gaussian width and mean as free parameters in the fit. Furthermore, an alternative method for the yield extraction based on counting the histogram entries in the signal invariant-mass region, after subtracting the background estimated from a fit to the sidebands, was considered. The absolute systematic uncertainties on v_2 due to the yield extraction range from 0.005 to 0.040 for D^0, D^+, and D^{*+} and from 0.015 to 0.070 for D_s^+ mesons. As a check of a possible efficiency dependence on $\Delta\varphi$, the analysis was repeated with different selection criteria, and no systematic effect was observed.

The EP resolution correction R_2 depends on collision centrality [34]. The value used in Eq. (1) was computed assuming a uniform distribution of the D-meson yield within the centrality class. This value was compared with those obtained from the weighted averages of the R_2 values in narrow centrality intervals, using as weights either the D-meson yields or the number of nucleon-nucleon collisions. In addition, to account for the presence of possible nonflow effects in the estimation of R_2, its value was recomputed using two different pseudorapidity gaps between the sub-events of the TPC tracks with positive or negative η. A systematic uncertainty of 2% on R_2 was estimated.

The v_2 of prompt D^0, D^+, D^{*+}, and D_s^+ mesons in the 30%–50% centrality class is shown in Fig. 1. The symbols

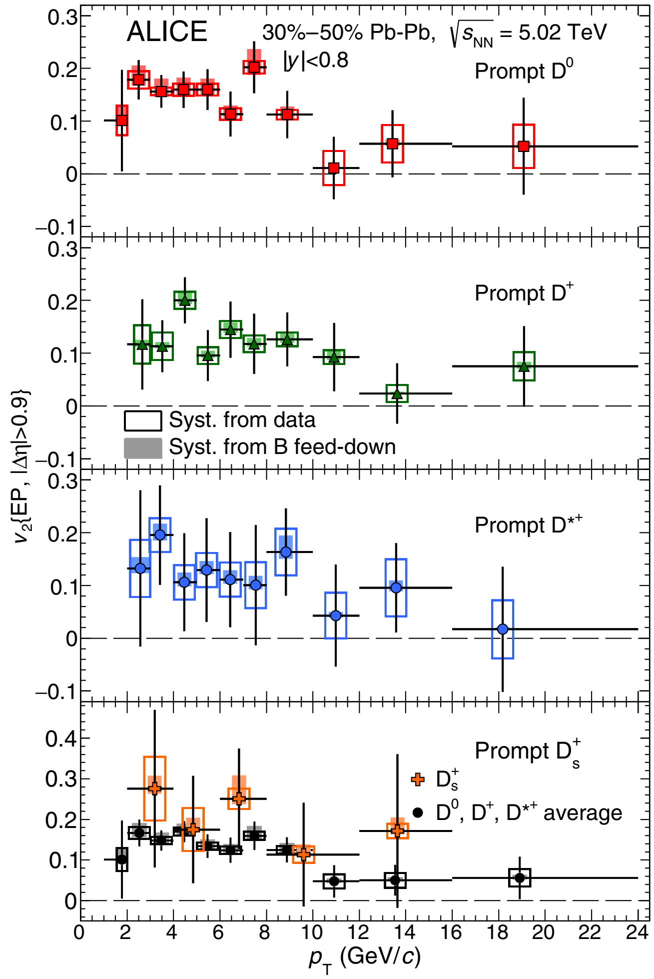

FIG. 1. Elliptic flow coefficient as a function of p_T for prompt D^0, D^+, D^{*+}, and D_s^+ mesons and their charge conjugates for Pb-Pb collisions in the centrality class 30%–50%. The bottom panel also shows the average v_2 of D^0, D^+, and D^{*+}. Vertical bars represent the statistical uncertainty, and empty boxes the systematic uncertainty associated with the D-meson anisotropy measurement and the event-plane resolution. Shaded boxes show the feed-down uncertainty.

are positioned at the average p_T of the reconstructed D mesons: this value was determined as the average of the p_T distribution of candidates in the signal invariant-mass region, after subtracting the contribution of the background candidates estimated from the sidebands. The v_2 of D^0, D^+, and D^{*+} are consistent, and they are larger than zero in $2 < p_T < 10$ GeV/c. The D^0 v_2 is compatible with the measurement by the CMS Collaboration [62]. The average of the v_2 measurements for D_s^+ mesons in the three p_T intervals within $2 < p_T < 8$ GeV/c is positive with a significance of 2.6σ, where σ is the uncertainty of the average v_2, calculated using quadratic propagation for the statistical and uncorrelated systematic uncertainties (signal extraction) and linear propagation for the correlated systematic uncertainties (R_2 and feed-down correction). The average v_2 and p_T of D^0, D^+, and D^{*+},

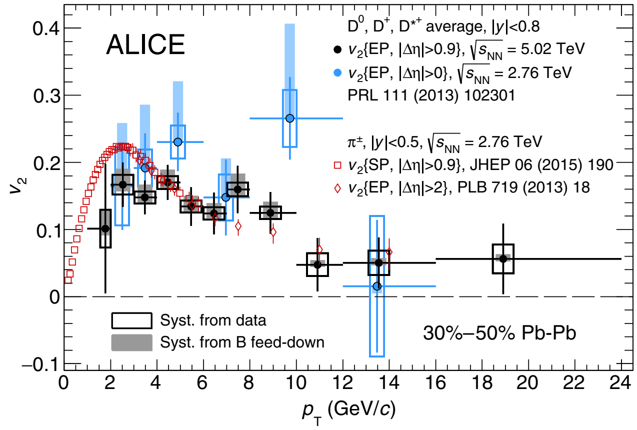

FIG. 2. Average of D^0, D^+, and D^{*+} v_2 as a function of p_T at $\sqrt{s_{NN}} = 5.02$ TeV, compared with the same measurement at $\sqrt{s_{NN}} = 2.76$ TeV [33] and to the $\pi^{\pm}$ v_2 measured with the EP method [63,64] and with the scalar production (SP) method [65].

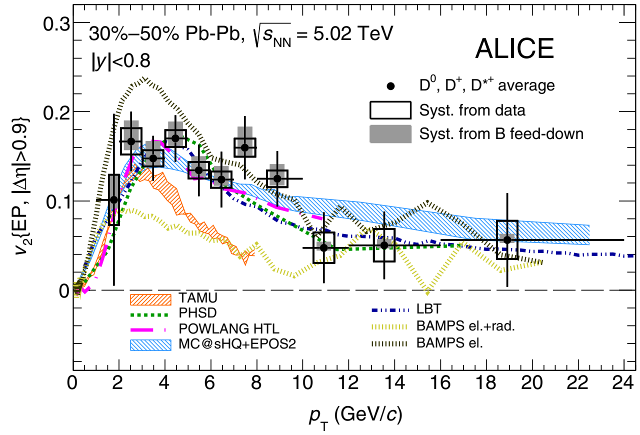

FIG. 3. Average of D^0, D^+, and D^{*+} v_2 as a function of p_T, compared with model calculations [38,42–46].

shown in the bottom panel in Fig. 1, was computed using the inverse of the squared statistical uncertainties as weights. The systematic uncertainties were propagated treating the R_2 and feed-down contributions as correlated among D-meson species.

Figure 2 shows that the average v_2 of D^0, D^+, and D^{*+} at $\sqrt{s_{NN}} = 5.02$ TeV is compatible with the same measurement at $\sqrt{s_{NN}} = 2.76$ TeV ($L_{\rm int} \approx 6\ \mu{\rm b}^{-1}$) [33], which has uncertainties larger by a factor of about 2 compared to the new result at 5.02 TeV. Note that the vertexing and tracking performance improved in 2015, and in Ref. [33] the correction for feed-down was made with the assumption $v_2^{\rm feed\text{-}down} = v_2^{\rm prompt}$. The assumption used in the present analysis, $v_2^{\rm feed\text{-}down} = v_2^{\rm prompt}/2$, would increase the values at $\sqrt{s_{NN}} = 2.76$ TeV by about 10%.

The average D-meson v_2 is also compared with the $\pi^{\pm}$ v_2 at $\sqrt{s_{NN}} = 2.76$ TeV measured with the EP method [63,64] considering a pseudorapidity separation of two units between $\pi^{\pm}$ and the particles used to measure the EP angle, and the scalar-product method [65], also based on two-particle correlations. The comparison of the D-meson v_2 at $\sqrt{s_{NN}} = 5.02$ TeV and of the pion v_2 at $\sqrt{s_{NN}} = 2.76$ TeV is justified by the observation that the p_T differential v_2 of charged particles, which is dominated by the pion component, is compatible at these two energies [66]. The D-meson v_2 is similar to that of $\pi^{\pm}$ in the common p_T interval (1–16 GeV/c), and it is lower in the interval below 4 GeV/c, the difference reaching about 2σ in 2–4 GeV/c, where a mass ordering of v_2 is observed for light-flavor hadrons and described by hydrodynamical calculations [65].

In Fig. 3, the average v_2 of the three nonstrange D-meson species is compared with theoretical calculations that include a hydrodynamical model for the QGP expansion (models that lack this expansion underestimated the D-meson v_2 measurements at $\sqrt{s_{NN}} = 2.76$ TeV in $2 < p_T < 6$ GeV/c [34]). The BAMPS-el [44], POWLANG [45], and TAMU [38] calculations include only collisional (i.e., elastic) interaction processes, while the BAMPS-el+rad [44], LBT [46], MC@sHQ [43], and PHSD [42] calculations also include energy loss via gluon radiation. All calculations, with the exception of BAMPS, include hadronization via quark recombination, in addition to independent fragmentation. The MC@sHQ and TAMU results are displayed with their theoretical uncertainty band. All calculations provide a fair description of the nuclear modification factor of D mesons in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in $1 < p_T < 8$ GeV/c [15].

The v_2 measurement at $\sqrt{s_{NN}} = 5.02$ TeV is described by most of these calculations, in which the interactions with the hydrodynamically expanding medium impart a positive v_2 to charm quarks. The model-to-data consistency was quantified using the reduced χ^2 in the p_T interval where all calculations are available (2–8 GeV/c): The LBT, MC@sHQ, PHSD, and POWLANG models have $\chi^2/{\rm ndf} < 1$, and the TAMU, BAMPS-el+rad, and BAMPS-el models have a $\chi^2/{\rm ndf}$ of 4.1, 6.7, and 1.9, respectively. The χ^2 calculation includes the data uncertainties and the model uncertainties when available. For BAMPS-el+rad, the low value of v_2 is caused by the absence of the recombination contribution [44]. For TAMU, the rapid decrease of v_2 with increasing p_T is due to the lack of radiative energy loss, which is also reflected in $R_{\rm AA}$ values larger than the measured ones at high p_T [15]. For most of these calculations, the medium effect on heavy quarks can be expressed using the dimensionless quantity $2\pi T D_s(T)$ [47]. In the interval from the critical temperature for QGP formation $T_c \approx 155$ MeV [2] to $2T_c$, the ranges of $2\pi T D_s(T)$ are 1–2 for BAMPS-el, 6–10 for BAMPS-el+rad, 2–6 for LBT [67], 1.5–4.5 for MC@sHQ [6], 4–9 for PHSD [42], 7–18 for POWLANG [10], and 4–10 for TAMU [6]. The calculations that describe the data with $\chi^2/{\rm ndf} < 1$ use $2\pi T D_s(T)$ in the range of 1.5–7 at T_c. Remarkably, this range is consistent with that obtained by the comparison of the D^0 v_2 in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV to model calculations [32], and it includes the values obtained by lattice QCD calculations [68,69] which are independent of the collision energy, because they encode a property of the medium evaluated at a fixed temperature. The corresponding thermalization time [47] for charm quarks is $\tau_{\rm charm} = (m_{\rm charm}/T)D_s(T) \approx 3$–$14\ {\rm fm}/c$ with $T = T_c$ and $m_{\rm charm} = 1.5\ {\rm GeV}/c^2$. These values are comparable to the estimated decoupling time of the high-density system [70]. It should also be pointed out that the models differ in several aspects, related to the medium expansion and the heavy quark-medium interactions both in the QGP and in the hadronic phase.

In summary, we have presented a measurement of the elliptic flow v_2 of prompt D^0, D^+, D^{*+}, and D_s^+ mesons in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The average v_2 of nonstrange D mesons was measured with statistical and systematic uncertainties smaller by a factor about 2 with respect to our measurement at $\sqrt{s_{NN}} = 2.76$ TeV. The results at the two energies are compatible within statistical uncertainties. The D_s^+ v_2 was for the first time measured at the LHC, although with a limited precision, and found to be compatible with that of nonstrange D mesons. The comparison of the D-meson v_2 with that of pions and with model calculations indicates that low-momentum charm quarks take part in the collective motion of the QGP and that collisional interaction processes as well as the recombination of charm and light quarks both contribute to the observed elliptic flow. The calculations that describe the measurements use heavy-quark spatial diffusion coefficients in the range of $2\pi T D_s(T) \approx 1.5$–$7$ at the critical temperature T_c.

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[1] F. Karsch, Lattice simulations of the thermodynamics of strongly interacting elementary particles and the exploration of new phases of matter in relativistic heavy ion collisions, J. Phys. Conf. Ser. **46**, 122 (2006).

[2] S. Borsanyi, Z. Fodor, C. Hoelbling, S. D. Katz, S. Krieg, C. Ratti, and K. K. Szabo (Wuppertal-Budapest Collaboration), Is there still any T_c mystery in lattice QCD? Results with physical masses in the continuum limit III, J. High Energy Phys. 09 (2010) 073.

[3] W. Florkowski, R. Ryblewski, N. Su, and K. Tywoniuk, Strong-coupling effects in a plasma of confining gluons, Nucl. Phys. **A956**, 669 (2016).

[4] A. Bazavov, T. Bhattacharya, M. Cheng, C. DeTar, H.-T. Ding, S. Gottlieb, R. Gupta, P. Hegde, U. M. Heller, F. Karsch, E. Laermann, L. Levkova, S. Mukherjee, P. Petreczky, C. Schmidt, R. A. Soltz, W. Soeldner, R. Sugar, D. Toussaint, W. Unger, and P. Vranas (HotQCD Collaboration), Chiral and deconfinement aspects of the QCD transition, Phys. Rev. D **85**, 054503 (2012).

[5] P. Braun-Munzinger, Quarkonium production in ultra-relativistic nuclear collisions: Suppression versus enhancement, J. Phys. G **34**, S471 (2007).

[6] A. Andronic *et al.*, Heavy-flavour and quarkonium production in the LHC era: From proton-proton to heavy-ion collisions, Eur. Phys. J. C **76**, 107 (2016).

[7] E. Braaten and M. H. Thoma, Energy loss of a heavy quark in the quark-gluon plasma, Phys. Rev. D **44**, R2625 (1991).

[8] M. Gyulassy and M. Plumer, Jet quenching in dense matter, Phys. Lett. B **243**, 432 (1990).

[9] R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne, and D. Schiff, Radiative energy loss and p(T) broadening of high-energy partons in nuclei, Nucl. Phys. **B484**, 265 (1997).

[10] F. Prino and R. Rapp, Open heavy flavor in QCD matter and in nuclear collisions, J. Phys. G **43**, 093002 (2016).

[11] A. Adare *et al.* (PHENIX Collaboration), Heavy quark production in $p+p$ and energy loss and flow of heavy quarks in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. C **84**, 044905 (2011).

[12] B. I. Abelev *et al.* (STAR Collaboration), Transverse Momentum and Centrality Dependence of High-p_T Nonphotonic Electron Suppression in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. **98**, 192301 (2007); Erratum, Phys. Rev. Lett. **106**, 159902 (2011).

[13] L. Adamczyk *et al.* (STAR Collaboration), Observation of D^0 Meson Nuclear Modifications in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. **113**, 142301 (2014).

[14] S. S. Adler *et al.* (PHENIX Collaboration), Nuclear Modification of Electron Spectra and Implications for Heavy Quark Energy Loss in Au + Au Collisions at $\sqrt{s_{NN}} =$ 200 GeV, Phys. Rev. Lett. **96**, 032301 (2006).

[15] J. Adam *et al.* (ALICE Collaboration), Transverse momentum dependence of D-meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 03 (2016) 081.

[16] B. Abelev *et al.* (ALICE Collaboration), Production of Muons from Heavy Flavor Decays at Forward Rapidity in pp and Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. Lett. **109**, 112301 (2012).

[17] J. Adam *et al.* (ALICE Collaboration), Measurement of the production of high-p_T electrons from heavy-flavour hadron decays in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **771**, 467 (2017).

[18] J. Adam *et al.* (ALICE Collaboration), Measurement of electrons from beauty-hadron decays in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and Pb-Pb collisions at $\sqrt{s_{NN}} =$ 2.76 TeV, J. High Energy Phys. 07 (2017) 052.

[19] V. Khachatryan *et al.* (CMS Collaboration), Suppression and azimuthal anisotropy of prompt and nonprompt J/ψ production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Eur. Phys. J. C **77**, 252 (2017).

[20] G.-Y. Qin, H. Petersen, S. A. Bass, and B. Muller, Translation of collision geometry fluctuations into momentum anisotropies in relativistic heavy-ion collisions, Phys. Rev. C **82**, 064903 (2010).

[21] S. Voloshin and Y. Zhang, Flow study in relativistic nuclear collisions by Fourier expansion of azimuthal particle distributions, Z. Phys. C **70**, 665 (1996).

[22] A. M. Poskanzer and S. A. Voloshin, Methods for analyzing anisotropic flow in relativistic nuclear collisions, Phys. Rev. C **58**, 1671 (1998).

[23] J.-Y. Ollitrault, Anisotropy as a signature of transverse collective flow, Phys. Rev. D **46**, 229 (1992).

[24] S. Batsouli, S. Kelly, M. Gyulassy, and J. L. Nagle, Does the charm flow at RHIC?, Phys. Lett. B **557**, 26 (2003).

[25] M. Gyulassy, I. Vitev, and X. N. Wang, High p(T) Azimuthal Asymmetry in Noncentral A + A at RHIC, Phys. Rev. Lett. **86**, 2537 (2001).

[26] E. V. Shuryak, Azimuthal asymmetry at large p_t seem to be too large for a pure "jet quenching", Phys. Rev. C **66**, 027902 (2002).

[27] D. Molnar, Charm elliptic flow from quark coalescence dynamics, J. Phys. G **31**, S421 (2005).

[28] A. Andronic, P. Braun-Munzinger, K. Redlich, and J. Stachel, Statistical hadronization of charm in heavy ion collisions at SPS, RHIC and LHC, Phys. Lett. B **571**, 36 (2003).

[29] V. Greco, C. M. Ko, and R. Rapp, Quark coalescence for charmed mesons in ultrarelativistic heavy ion collisions, Phys. Lett. B **595**, 202 (2004).

[30] M. He, R. J. Fries, and R. Rapp, D_s-Meson as a Quantitative Probe of Diffusion and Hadronization in Nuclear Collisions, Phys. Rev. Lett. **110**, 112301 (2013).

[31] L. Adamczyk *et al.* (STAR Collaboration), Elliptic flow of electrons from heavy-flavor hadron decays in Au + Au

collisions at $\sqrt{s_{NN}} = 200$, 62.4, and 39 GeV, Phys. Rev. C **95**, 034907 (2017).

[32] L. Adamczyk *et al.* (STAR Collaboration), Measurement of D^0 Azimuthal Anisotropy at Midrapidity in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. **118**, 212301 (2017).

[33] B. Abelev *et al.* (ALICE Collaboration), D-meson Elliptic Flow in Noncentral Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. Lett. **111**, 102301 (2013).

[34] B. Abelev *et al.* (ALICE Collaboration), Azimuthal anisotropy of D-meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C **90**, 034904 (2014).

[35] J. Adam *et al.* (ALICE Collaboration), Elliptic flow of electrons from heavy-flavour hadron decays at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 09 (2016) 028.

[36] J. Adam *et al.* (ALICE Collaboration), Elliptic flow of muons from heavy-flavour hadron decays at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **753**, 41 (2016).

[37] J. Uphoff, O. Fochler, Z. Xu, and C. Greiner, Open heavy flavor in Pb + Pb collisions at $\sqrt{s} = 2.76$ TeV within a transport model, Phys. Lett. B **717**, 430 (2012).

[38] M. He, R. J. Fries, and R. Rapp, Heavy flavor at the Large Hadron Collider in a strong coupling approach, Phys. Lett. B **735**, 445 (2014).

[39] M. Monteno, W. M. Alberico, A. Beraudo, A. De Pace, A. Molinari, M. Nardi, and F. Prino, Heavy-flavor dynamics in nucleus-nucleus collisions: From RHIC to LHC, J. Phys. G **38**, 124144 (2011).

[40] M. Djordjevic and M. Djordjevic, Predictions of heavy-flavor suppression at 5.1 TeV Pb + Pb collisions at the CERN Large Hadron Collider, Phys. Rev. C **92**, 024918 (2015).

[41] S. Cao, G.-Y. Qin, and S. A. Bass, Heavy-quark dynamics and hadronization in ultrarelativistic heavy-ion collisions: Collisional versus radiative energy loss, Phys. Rev. C **88**, 044907 (2013).

[42] T. Song, H. Berrehrah, D. Cabrera, W. Cassing, and E. Bratkovskaya, Charm production in Pb + Pb collisions at energies available at the CERN Large Hadron Collider, Phys. Rev. C **93**, 034906 (2016).

[43] M. Nahrgang, J. Aichelin, P. B. Gossiaux, and K. Werner, Influence of hadronic bound states above T_c on heavy-quark observables in Pb + Pb collisions at the CERN Large Hadron Collider, Phys. Rev. C **89**, 014905 (2014).

[44] J. Uphoff, O. Fochler, Z. Xu, and C. Greiner, Elastic and radiative heavy quark interactions in ultra-relativistic heavy-ion collisions, J. Phys. G **42**, 115106 (2015).

[45] A. Beraudo, A. De Pace, M. Monteno, M. Nardi, and F. Prino, Heavy flavors in heavy-ion collisions: Quenching, flow and correlations, Eur. Phys. J. C **75**, 121 (2015).

[46] S. Cao, T. Luo, G.-Y. Qin, and X.-N. Wang, Heavy and light flavor jet quenching at RHIC and LHC energies, Phys. Lett. B **777**, 255 (2018).

[47] G. D. Moore and D. Teaney, How much do heavy quarks thermalize in a heavy ion collision?, Phys. Rev. C **71**, 064904 (2005).

[48] K. Aamodt *et al.* (ALICE Collaboration), The ALICE experiment at the CERN LHC, J. Instrum. **3**, S08002 (2008).

[49] B. Abelev *et al.* (ALICE Collaboration), Performance of the ALICE experiment at the CERN LHC, Int. J. Mod. Phys. A **29**, 1430044 (2014).

[50] B. Abelev *et al.* (ALICE Collaboration), Centrality determination of Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE, Phys. Rev. C **88**, 044909 (2013).

[51] J. Adam *et al.* (ALICE Collaboration), Centrality Dependence of the Charged-Particle Multiplicity Density at Midrapidity in Pb-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Rev. Lett. **116**, 222302 (2016).

[52] J. Adam *et al.* (ALICE Collaboration), Measurement of D_s^+ production and nuclear modification factor in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 03 (2016) 082.

[53] C. Patrignani *et al.* (Particle Data Group), Review of particle physics, Chin. Phys. C **40**, 100001 (2016).

[54] I. Selyuzhenkov and S. Voloshin, Effects of nonuniform acceptance in anisotropic flow measurements, Phys. Rev. C **77**, 034904 (2008).

[55] J. Aichelin, P. B. Gossiaux, and T. Gousset, Radiative and collisional energy loss of heavy quarks in deconfined matter, Acta Phys. Pol. B **43**, 655 (2012).

[56] V. Greco, H. van Hees, and R. Rapp, in *Proceedings of the 23rd International Conference on Nuclear Physics, INPC 2007, Tokyo, Japan, 2007* (unpublished) [arXiv:0709.4452].

[57] B. Abelev *et al.* (ALICE Collaboration), Suppression of high transverse momentum D-mesons in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 09 (2012) 112.

[58] M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason, and G. Ridolfi, Theoretical predictions for charm and bottom production at the LHC, J. High Energy Phys. 10 (2012) 137.

[59] D. J. Lange, The EvtGen particle decay simulation package, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[60] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Glauber modeling in high energy nuclear collisions, Annu. Rev. Nucl. Part. Sci. **57**, 205 (2007).

[61] J. Adam *et al.* (ALICE Collaboration), Centrality dependence of high-p_T D-meson suppression in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 11 (2015) 205.

[62] A. M. Sirunyan *et al.* (CMS Collaboration), Measurement of prompt D^0-meson azimuthal anisotropy in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, arXiv:1708.03497.

[63] B. Abelev *et al.* (ALICE Collaboration), Anisotropic flow of charged hadrons, pions and (anti-)protons measured at high transverse momentum in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **719**, 18 (2013).

[64] ALICE Collaboration, public note, 2015, http://cds.cern.ch/record/2045885.

[65] B. Abelev *et al.* (ALICE Collaboration), Elliptic flow of identified hadrons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 06 (2015) 190.

[66] J. Adam *et al.* (ALICE Collaboration), Anisotropic Flow of Charged Particles in Pb-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Rev. Lett. **116**, 132302 (2016).

[67] Y. Xu, M. Nahrgang, J. E. Bernhard, S. Cao, and S. A. Bass, A data-driven analysis of the heavy quark transport coefficient, Nucl. Phys. **A967**, 668 (2017).
[68] H. T. Ding, A. Francis, O. Kaczmarek, F. Karsch, H. Satz, and W. Soeldner, Charmonium properties in hot quenched lattice QCD, Phys. Rev. D **86**, 014509 (2012).
[69] D. Banerjee, S. Datta, R. Gavai, and P. Majumdar, Heavy quark momentum diffusion coefficient from lattice QCD, Phys. Rev. D **85**, 014510 (2012).
[70] K. Aamodt *et al.* (ALICE Collaboration), Two-pion Bose-Einstein correlations in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B **696**, 328 (2011).

S. Acharya,[139] D. Adamová,[96] J. Adolfsson,[34] M. M. Aggarwal,[101] G. Aglieri Rinella,[35] M. Agnello,[31] N. Agrawal,[48] Z. Ahammed,[139] N. Ahmad,[17] S. U. Ahn,[80] S. Aiola,[143] A. Akindinov,[65] S. N. Alam,[139] J. L. B. Alba,[114] D. S. D. Albuquerque,[125] D. Aleksandrov,[92] B. Alessandro,[59] R. Alfaro Molina,[75] A. Alici,[54,27,12] A. Alkin,[3] J. Alme,[22] T. Alt,[71] L. Altenkamper,[22] I. Altsybeev,[138] C. Alves Garcia Prado,[124] C. Andrei,[89] D. Andreou,[35] H. A. Andrews,[113] A. Andronic,[109] V. Anguelov,[106] C. Anson,[99] T. Antičić,[110] F. Antinori,[57] P. Antonioli,[54] R. Anwar,[127] L. Aphecetche,[117] H. Appelshäuser,[71] S. Arcelli,[27] R. Arnaldi,[59] O. W. Arnold,[107,36] I. C. Arsene,[21] M. Arslandok,[106] B. Audurier,[117] A. Augustinus,[35] R. Averbeck,[109] M. D. Azmi,[17] A. Badalà,[56] Y. W. Baek,[61,79] S. Bagnasco,[59] R. Bailhache,[71] R. Bala,[103] A. Baldisseri,[76] M. Ball,[45] R. C. Baral,[68] A. M. Barbano,[26] R. Barbera,[28] F. Barile,[33,53] L. Barioglio,[26] G. G. Barnaföldi,[142] L. S. Barnby,[95] V. Barret,[82] P. Bartalini,[7] K. Barth,[35] E. Bartsch,[71] M. Basile,[27] N. Bastid,[82] S. Basu,[141] G. Batigne,[117] B. Batyunya,[78] P. C. Batzing,[21] I. G. Bearden,[93] H. Beck,[106] C. Bedda,[64] N. K. Behera,[61] I. Belikov,[135] F. Bellini,[27] H. Bello Martinez,[2] R. Bellwied,[127] L. G. E. Beltran,[123] V. Belyaev,[85] G. Bencedi,[142] S. Beole,[26] A. Bercuci,[89] Y. Berdnikov,[98] D. Berenyi,[142] R. A. Bertens,[130] D. Berzano,[35] L. Betev,[35] A. Bhasin,[103] I. R. Bhat,[103] A. K. Bhati,[101] B. Bhattacharjee,[44] J. Bhom,[121] L. Bianchi,[127] N. Bianchi,[51] C. Bianchin,[141] J. Bielčík,[39] J. Bielčíková,[96] A. Bilandzic,[36,107] G. Biro,[142] R. Biswas,[4] S. Biswas,[4] J. T. Blair,[122] D. Blau,[92] C. Blume,[71] G. Boca,[136] F. Bock,[106,84,35] A. Bogdanov,[85] L. Boldizsár,[142] M. Bombara,[40] G. Bonomi,[137] M. Bonora,[35] J. Book,[71] H. Borel,[76] A. Borissov,[19] M. Borri,[129] E. Botta,[26] C. Bourjau,[93] L. Bratrud,[71] P. Braun-Munzinger,[109] M. Bregant,[124] T. A. Broker,[71] M. Broz,[39] E. J. Brucken,[46] E. Bruna,[59] G. E. Bruno,[33] D. Budnikov,[111] H. Buesching,[71] S. Bufalino,[31] P. Buhler,[116] P. Buncic,[35] O. Busch,[133] Z. Buthelezi,[77] J. B. Butt,[15] J. T. Buxton,[18] J. Cabala,[119] D. Caffarri,[35,94] H. Caines,[143] A. Caliva,[64] E. Calvo Villar,[114] P. Camerini,[25] A. A. Capon,[116] F. Carena,[35] W. Carena,[35] F. Carnesecchi,[27,12] J. Castillo Castellanos,[76] A. J. Castro,[130] E. A. R. Casula,[55] C. Ceballos Sanchez,[9] P. Cerello,[59] S. Chandra,[139] B. Chang,[128] S. Chapeland,[35] M. Chartier,[129] J. L. Charvet,[76] S. Chattopadhyay,[139] S. Chattopadhyay,[112] A. Chauvin,[36,107] M. Cherney,[99] C. Cheshkov,[134] B. Cheynis,[134] V. Chibante Barroso,[35] D. D. Chinellato,[125] S. Cho,[61] P. Chochula,[35] K. Choi,[19] M. Chojnacki,[93] S. Choudhury,[139] T. Chowdhury,[82] P. Christakoglou,[94] C. H. Christensen,[93] P. Christiansen,[34] T. Chujo,[133] S. U. Chung,[19] C. Cicalo,[55] L. Cifarelli,[12,27] F. Cindolo,[54] J. Cleymans,[102] F. Colamaria,[33] D. Colella,[35,66] A. Collu,[84] M. Colocci,[27] M. Concas,[59,‡] G. Conesa Balbastre,[83] Z. Conesa del Valle,[62] M. E. Connors,[143,§] J. G. Contreras,[39] T. M. Cormier,[97] Y. Corrales Morales,[59] I. Cortés Maldonado,[2] P. Cortese,[32] M. R. Cosentino,[126] F. Costa,[35] S. Costanza,[136] J. Crkovská,[62] P. Crochet,[82] E. Cuautle,[73] L. Cunqueiro,[72] T. Dahms,[36,107] A. Dainese,[57] M. C. Danisch,[106] A. Danu,[69] D. Das,[112] I. Das,[112] S. Das,[4] A. Dash,[90] S. Dash,[48] S. De,[124,49] A. De Caro,[30] G. de Cataldo,[53] C. de Conti,[124] J. de Cuveland,[42] A. De Falco,[24] D. De Gruttola,[30,12] N. De Marco,[59] S. De Pasquale,[30] R. D. De Souza,[125] H. F. Degenhardt,[124] A. Deisting,[109,106] A. Deloff,[88] C. Deplano,[94] P. Dhankher,[48] D. Di Bari,[33] A. Di Mauro,[35] P. Di Nezza,[51] B. Di Ruzza,[57] M. A. Diaz Corchero,[10] T. Dietel,[102] P. Dillenseger,[71] R. Divià,[35] Ø. Djuvsland,[22] A. Dobrin,[35] D. Domenicis Gimenez,[124] B. Dönigus,[71] O. Dordic,[21] L. V. V. Doremalen,[64] A. K. Dubey,[139] A. Dubla,[109] L. Ducroux,[134] A. K. Duggal,[101] P. Dupieux,[82] R. J. Ehlers,[143] D. Elia,[53] E. Endress,[114] H. Engel,[70] E. Epple,[143] B. Erazmus,[117] F. Erhardt,[100] B. Espagnon,[62] S. Esumi,[133] G. Eulisse,[35] J. Eum,[19] D. Evans,[113] S. Evdokimov,[115] L. Fabbietti,[107,36] J. Faivre,[83] A. Fantoni,[51] M. Fasel,[97,84] L. Feldkamp,[72] A. Feliciello,[59] G. Feofilov,[138] J. Ferencei,[96] A. Fernández Téllez,[2] E. G. Ferreiro,[16] A. Ferretti,[26] A. Festanti,[29,35] V. J. G. Feuillard,[76,82] J. Figiel,[121] M. A. S. Figueredo,[124] S. Filchagin,[111] D. Finogeev,[63] F. M. Fionda,[22,24] E. M. Fiore,[33] M. Floris,[35] S. Foertsch,[77] P. Foka,[109] S. Fokin,[92] E. Fragiacomo,[60] A. Francescon,[35] A. Francisco,[117] U. Frankenfeld,[109] G. G. Fronze,[26] U. Fuchs,[35] C. Furget,[83] A. Furs,[63] M. Fusco Girard,[30] J. J. Gaardhøje,[93] M. Gagliardi,[26] A. M. Gago,[114] K. Gajdosova,[93] M. Gallio,[26] C. D. Galvan,[123] P. Ganoti,[87] C. Gao,[7] C. Garabatos,[109] E. Garcia-Solis,[13] K. Garg,[28] C. Gargiulo,[35] P. Gasik,[36,107] E. F. Gauger,[122] M. B. Gay Ducati,[74] M. Germain,[117] J. Ghosh,[112] P. Ghosh,[139] S. K. Ghosh,[4] P. Gianotti,[51] P. Giubellino,[109,59,35] P. Giubilato,[29] E. Gladysz-Dziadus,[121] P. Glässel,[106] D. M. Goméz Coral,[75] A. Gomez Ramirez,[70]

A. S. Gonzalez,[35] V. Gonzalez,[10] P. González-Zamora,[10] S. Gorbunov,[42] L. Görlich,[121] S. Gotovac,[120] V. Grabski,[75] L. K. Graczykowski,[140] K. L. Graham,[113] L. Greiner,[84] A. Grelli,[64] C. Grigoras,[35] V. Grigoriev,[85] A. Grigoryan,[1] S. Grigoryan,[78] N. Grion,[60] J. M. Gronefeld,[109] F. Grosa,[31] J. F. Grosse-Oetringhaus,[35] R. Grosso,[109] L. Gruber,[116] F. Guber,[63] R. Guernane,[83] B. Guerzoni,[27] K. Gulbrandsen,[93] T. Gunji,[132] A. Gupta,[103] R. Gupta,[103] I. B. Guzman,[2] R. Haake,[35] C. Hadjidakis,[62] H. Hamagaki,[86,132] G. Hamar,[142] J. C. Hamon,[135] M. R. Haque,[64] J. W. Harris,[143] A. Harton,[13] H. Hassan,[83] D. Hatzifotiadou,[12,54] S. Hayashi,[132] S. T. Heckel,[71] E. Hellbär,[71] H. Helstrup,[37] A. Herghelegiu,[89] G. Herrera Corral,[11] F. Herrmann,[72] B. A. Hess,[105] K. F. Hetland,[37] H. Hillemanns,[35] C. Hills,[129] B. Hippolyte,[135] J. Hladky,[67] B. Hohlweger,[107] D. Horak,[39] S. Hornung,[109] R. Hosokawa,[83,133] P. Hristov,[35] C. Hughes,[130] T. J. Humanic,[18] N. Hussain,[44] T. Hussain,[17] D. Hutter,[42] D. S. Hwang,[20] S. A. Iga Buitron,[73] R. Ilkaev,[111] M. Inaba,[133] M. Ippolitov,[85,92] M. Irfan,[17] V. Isakov,[63] M. Ivanov,[109] V. Ivanov,[98] V. Izucheev,[115] B. Jacak,[84] N. Jacazio,[27] P. M. Jacobs,[84] M. B. Jadhav,[48] J. Jadlovsky,[119] S. Jaelani,[64] C. Jahnke,[36] M. J. Jakubowska,[140] M. A. Janik,[140] P. H. S. Y. Jayarathna,[127] C. Jena,[90] S. Jena,[127] M. Jercic,[100] R. T. Jimenez Bustamante,[109] P. G. Jones,[113] A. Jusko,[113] P. Kalinak,[66] A. Kalweit,[35] J. H. Kang,[144] V. Kaplin,[85] S. Kar,[139] A. Karasu Uysal,[81] O. Karavichev,[63] T. Karavicheva,[63] L. Karayan,[109,106] P. Karczmarczyk,[35] E. Karpechev,[63] U. Kebschull,[70] R. Keidel,[145] D. L. D. Keijdener,[64] M. Keil,[35] B. Ketzer,[45] Z. Khabanova,[94] P. Khan,[112] S. A. Khan,[139] A. Khanzadeev,[98] Y. Kharlov,[115] A. Khatun,[17] A. Khuntia,[49] M. M. Kielbowicz,[121] B. Kileng,[37] B. Kim,[133] D. Kim,[144] D. J. Kim,[128] H. Kim,[144] J. S. Kim,[43] J. Kim,[106] M. Kim,[61] M. Kim,[144] S. Kim,[20] T. Kim,[144] S. Kirsch,[42] I. Kisel,[42] S. Kiselev,[65] A. Kisiel,[140] G. Kiss,[142] J. L. Klay,[6] C. Klein,[71] J. Klein,[35] C. Klein-Bösing,[72] S. Klewin,[106] A. Kluge,[35] M. L. Knichel,[106] A. G. Knospe,[127] C. Kobdaj,[118] M. Kofarago,[142] T. Kollegger,[109] A. Kolojvari,[138] V. Kondratiev,[138] N. Kondratyeva,[85] E. Kondratyuk,[115] A. Konevskikh,[63] M. Konyushikhin,[141] M. Kopcik,[119] M. Kour,[103] C. Kouzinopoulos,[35] O. Kovalenko,[88] V. Kovalenko,[138] M. Kowalski,[121] G. Koyithatta Meethaleveedu,[48] I. Králik,[66] A. Kravčáková,[40] M. Krivda,[66,113] F. Krizek,[96] E. Kryshen,[98] M. Krzewicki,[42] A. M. Kubera,[18] V. Kučera,[96] C. Kuhn,[135] P. G. Kuijer,[94] A. Kumar,[103] J. Kumar,[48] L. Kumar,[101] S. Kumar,[48] S. Kundu,[90] P. Kurashvili,[88] A. Kurepin,[63] A. B. Kurepin,[63] A. Kuryakin,[111] S. Kushpil,[96] M. J. Kweon,[61] Y. 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